TRANS 378

USTANOVKA DLYA IZMERENIYA INTENSIVNOSTI KOSMICHESKIKH LUCHEY NA BOL'SHIKH GLUBINAKH

(Apparatus for Measuring the Intensity of Cosmic Rays at Great Depths)

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METODY I PRIBORY DLYA ISSLEDOVANIYA
FIZICHESKIKH PROTSESSOV V OKEANE

Marine Hydrophysical Institute
VOL. 36
Pp. 31-36

KIEV 1966

Translator: M. Slessers
Typed by : C. Sims

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C.
1967

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ABSTRACT

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The use of a Cherenkov detector is suggested for the measurement of intensity of μ-mesons at great depths. The detector was tested in the Black Sea at depths as great as 1km. A diagram shows the recorded impulses. Some of the calculated values are tabulated to show the expected global intensity to depths of 5km which had been calculated with the aid of theoretically derived ratios for the vertical intensity of μ-mesons.

yrll

Translator

APPARATUS FOR MEASURING THE INTENSITY OF COSMIC RAYS AT GREAT DEPTHS

Experimental data on the dependence of intensity of cosmic rays upon the depth of absorber has for many years attracted the attention of physicists, who investigate cosmic rays and elementary particles.

During the first period of investigations, the tests aimed at the determination of relationship between the intensity of cosmic rays and the depth disclosed that the absorption coefficient of cosmic rays in water is ten times smaller than the absorption coefficient of γ-rays, and that, therefore, the cosmic rays are not γ-rays.

It is known that all of the cosmic rays that are recorded under the earth and under water beginning from the depth of 20m consist of the so-called μ-mesons which are the most penetrating of the elementary particles, except for the neutrino.

We shall discuss why the tests dealing with the variation of intensity of μ-mesons in matter at great depths is of interest to the physics of high energy particles and cosmic rays (at depths exceeding 1000m, of special interest being depths exceeding 5000m). The measurement of the relation between the intensity of cosmic radiation at great depths (1000-8000m of the water equivalent*) and the depth (absorption curve) and the comparison /32 of the resultant "absorption curve" with theoretical calculations enables us to verify the theory of interaction of high energy 10^{11}-10^{13} ev) μ-mesons.

This theory is based on the use of quantum electrodynamics in connection with μ-meson. Thus the possibility in the application of the quantum electrodynamics to this elementary particle is verified.

Many of the processes of interaction between the μ-mesons of high energies and the matter, which results in their absorption have not yet been sufficiently investigated.

*It is extremely difficult to obtain data on the intensity of cosmic radiation at the depths of 8000m because the flux of μ-mesons is insignificant at such depths.

Let us discuss the character of absorption of μ-mesons of high energy by the matter. The energy losses can be written as follows [1]:

$$\frac{dE}{dx} = a + (b_\tau + b_n + b_\pi) E,$$

where E=energy of μ-meson; x=depth of absorber, g/cm^2; a=term that characterized the ionnization losses of high speed particles, which increases with the increase of energy in accordance with the logarithmic law

$$a = a_0 + c \ln E;$$

b_t=coefficient associated with losses due to bremsstrahlung (breaking radiation) of μ-mesons (in the process of bremsstrahlung the μ-meson transfers the energy to the γ-quanta); b_π=coefficient defining the so-called photonuclear loss of energy of μ-meson to the formation of electronic-nuclear showers where the charged and neutral π-mesons are, as a rule, generated.

Generally, the μ-meson is a nuclear-particle, but it has an electromagnetic field which can interact with the nuclei of atoms. One can observe the photonuclear effect which is analogous the one that is obtained in interaction between γ-quanta and nuclei in tests with accelerators. However, in the case of μ-mesons, one can observe the nuclear interaction of individual virtual photons, into which the electromagnetic field of the arriving μ-meson can be decomposed by the theory of quantum electrodynamics.

Experimentally, the interaction of the actual quanta with nucleons and nuclei has been studied only with regard to the energy of γ-quanta of the order of several billions of electron-volts. Meanwhile, in tests with cosmic μ-mesons when they generate electro-nuclear showers one can observe the interaction with the matter of the virtual γ-quanta with energy near that of μ-mesons. Consequently, if the nuclear interactions with μ-mesons having energies of the order of 10^{12}-10^{13} ev are considered, γ-quanta of the same order of energy are responsible for the interactions, which is exceptional theoretical significance.

At the present time, only the terms a and b_t have been calculated with a sufficient accuracy. The expression b_π is less accurate (10%). Because of this and also because of incomplete knowledge of the energy spectrum of μ-mesons when the energy level is about $\gtrsim 5\text{x}10^{11}$ ev at sea level, it is impossible by using the known ratio of intensity of μ-mesons to the depth in one medium, to determine the coefficient b_π with an accuracy better than ≈100%. /33

If, however, the experimental data on this ratio are determined for two media: soil and water, the nuclear losses can be calculated with a greater accuracy notwithstanding the fact that the energetic spectrum of μ-mesons has not yet been completely investigated. Indeed, if ratio of intensity to the depth of absorber for two media (sea bottom-water) is plotted, and if the latter is expressed by special length units proportional to parameter $\frac{A}{Z^2}$ (where A=mean atomic weight of the medium and Z=the atomic number of nucl , we find that, with the absence of nuclear losses, the curves of intensity vs depth would coincide for the two media when such a method of plotting is employed. The divergence of the curves will depend upon the magnitudes of nuclear losses relative to electromagnetic losses [2].

Data on the intensity of cosmic radiation at various depth levels, including the maximum values, are of great interest for nuclear physics and biology. Evidently, the cosmic radiation is one of the external factors creating very rare genetic mutations in the few live beings that were found at very great depths [3]. Consequently, the cosmic radiation at these depths can, at least partially, affect the rate of evolution of these organisms.

In this paper we suggest the use of a Cherenkov detector for the measurement of intensity of μ-mesons at great depths. The detector was constructed by us and tested in the Black Sea at depths as great as 1km.

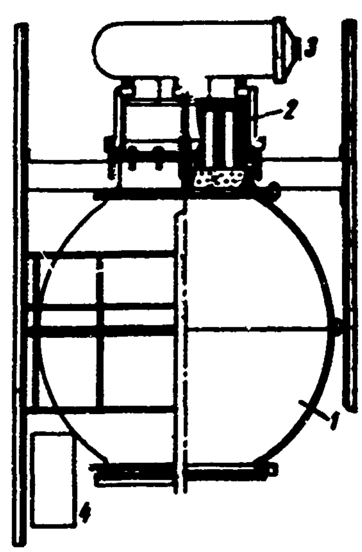

FIG. 1

The diagram of the detector is presented in Fig. 1, where 1= the frame of calculator; 2=container ФЭУ; 3=container with electronic device; 4=accumulator. Water is poured into the body of the detector to be used as a radiator; its form is spherical and it is made of plastic glass; the total weight is 60kg. The /34 external diameter of the sphere is 1.2m. The working volume of the detector is $\approx 1m^3$. The inside of the sphere has been painted by a special diffuse light-scattering paint, which is water resistant, its refraction coefficient being 90%. The spherical coating of the detector facilitates the use of the instrument in sea. When μ-meson passes through the detector submerged in water, the Cherenkov radiation takes place. If the μ-meson passes a distance equalling the diameter of the sphere, approximately 2.10^4 photons of the Cherenkov radiation are created, their wave lengths ranging from 2900 to 6000 Å. This radiation is recorded by fifteen photo-multipliers ФЭУ: the photocathode diameter being 8cm. When a small amount of fluorescent salt of amin-F acid (~20-40g) is added to the water, the spectrum of the created photons of the Cherenkov radiation is displaced from the band 2900-3500 Å to the band 4500-5500 Å in which the maximum of spectral sensitivity of photocathodes of photo-multipliers is observed.

The photo-multipliers are divided into three groups, five in each. /35 Only triple coincidences of light impulses of each ФЭУ group are recorded.

The diagram showing the recording of impulses is presented in Fig. 2. Impulses from each of the five ФЭУ of each group of photo-multipliers enter, after emitter (ЭП), the primary winding of the impulse transformer where they are summed up. After the impulse transformer, the impulses that have been preamplified reach the amplifers, then discriminators. After discrimination the impulses travel to the coincidence device in a calculated time 0.5 microseconds. The impulses are recorded on the tape of an automatic recorder which is set in operation by an electronic motor. In addition to marks of each recorded impulse, the time is recorded on the tape by special contacts on the clock.

The electronic devices are powered by batteries of the type HKH-100 and CTЭ-100 with the aid of semiconductor regulators and transformers from low voltage to high voltage. The semiconductor transformers regulate the high voltage within 0.3-0.5%.

The effectiveness of recording single μ-mesons that pass the distance of 1m through the detector at angles near the vertical was 99±1%; it was determined by special tests. The Cherenov detector was placed among three rows of Geiger counters. The impulses of

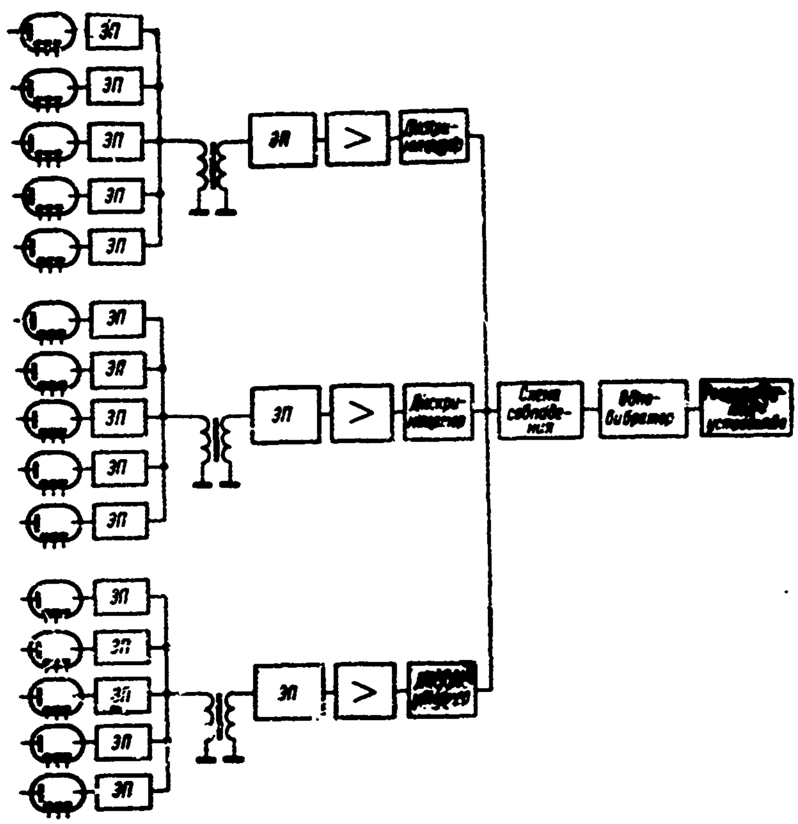

FIG. 2

KEY (From top to bottom): Discriminator

Discr. Coincidence Single vibrator Recording unit

Discriminator

triple coincidence on the Geiger counters corresponded to the /35
passage of μ-meson through the actual (working) volume of the Cherenkov calculator. The percentage of coincidence between these impulses corresponded to the effectiveness of recording μ-meson detector which traveled almost the distance of the calculator diameter.

In November 1964, the detector was tested during the cruise of the Moskovskiy Universitet. The entire mechanical portion of the detector was verified, as well as the operation of electronic devices.

Data on the intensity of cosmic rays at sea level (0m) and at the depth of 8m, as well as preliminary data on it at the depths of 500 and 1000m are listed in a table. The table shows the calculated values of the expected global intensity to a depth of 5km, which were calculated with the aid of theoretically derived ratios for vertical intensity of μ-mesons in dependence upon the depth in water [2]. The table makes it possible to appraise the exposure time of the instrument at various depths, which is necessary for obtaining the given statistical accuracy in the value of the intensity of μ-mesons.

The authors express a sincere gratitude to Prof. A. G. Kolesnikov for enabling us to conduct a joint research with FIAN and MGI AN USSR and to the management of the Faculty of Physics of the /36
Moscow State University for aiding the testing of the instrument on the research vessel Moskovskiy Universitet.

Depth, m	Global Intensity of cosmic rays per $1m^2$	
	calculated	recorded
0	160 $сек^{-1}$	(196±1) $сек^{-1}$
8	100 $сек^{-1}$	(94±1) $сек^{-1}$
500	540 $час^{-1}$	(450±20) $час^{-1}$
1000	110 $час^{-4}$	(105±10) $час^{-1}$
1500	36 $час^{-1}$	—
2000	15 $час^{-1}$	—
3000	85 $суток^{-1}$	—
4000	18 $суток^{-1}$	—
5000	5 $суток^{-1}$	—

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